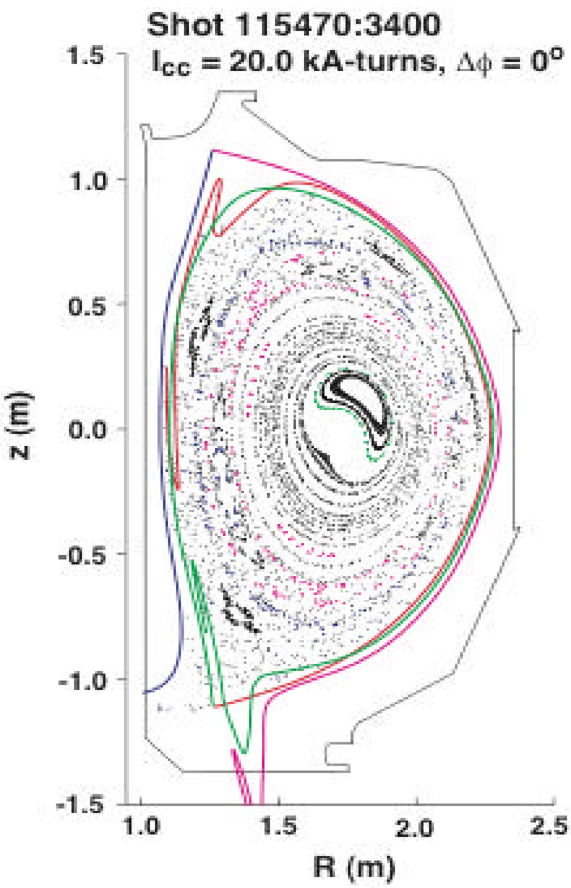
Integrated 3D pedestal, SOL and divertor modeling - a critical step for solving the ITER ELM and PMI problems



T. E. Evans

General Atomics, San Diego, CA, USA

Plasma Facing Component Meeting,
17-20 November 2003,
Argonne National Laboratory, Oakbrook, Il

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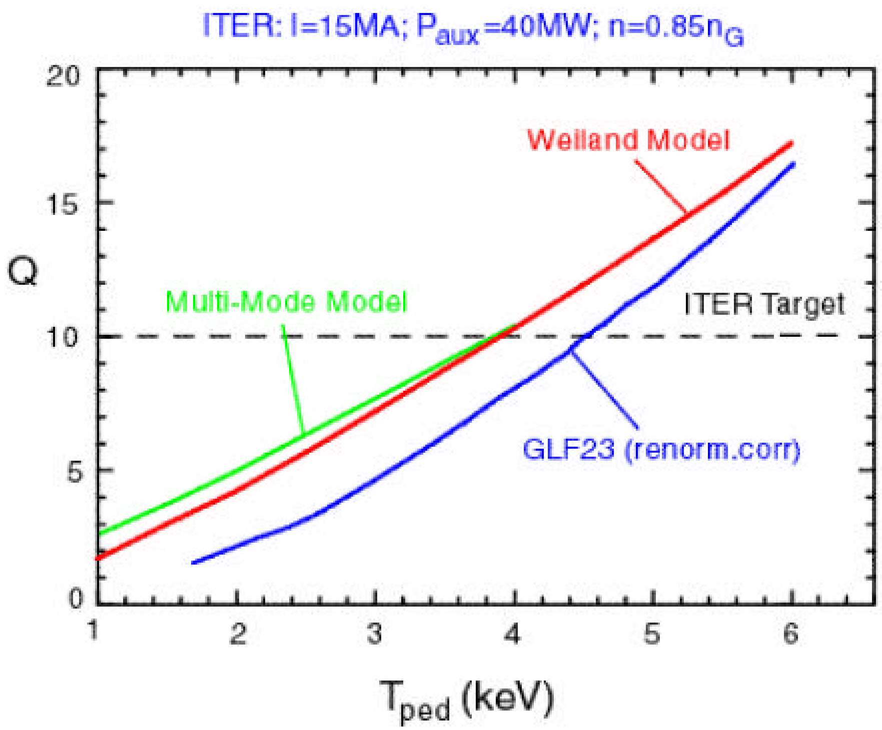
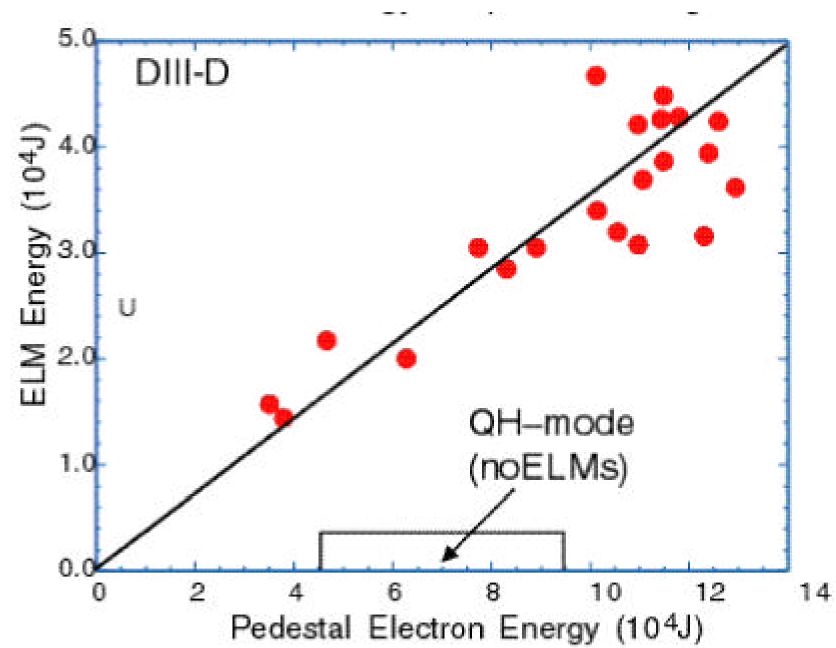
ELMs are the most serious issue facing ITER





- Core performance is tightly coupled to pedestal height by stiff radial transport
  - > Both the uncertainty in the transport models and in the pedestal T_e affects the predictibality of Q_{fusoin} ITER
- ELMs provide a steady-state operating regime with good energy/particle exhaust and acceptable core impurity levels

- ELMs affect core plasma performance...
  - > Directly by reducing pedestal height
  - > Indirectly by affecting pedestal stability
- **ELMs limit the divertor plate lifetime**
  - > **Impulsive heat flux erodes material**

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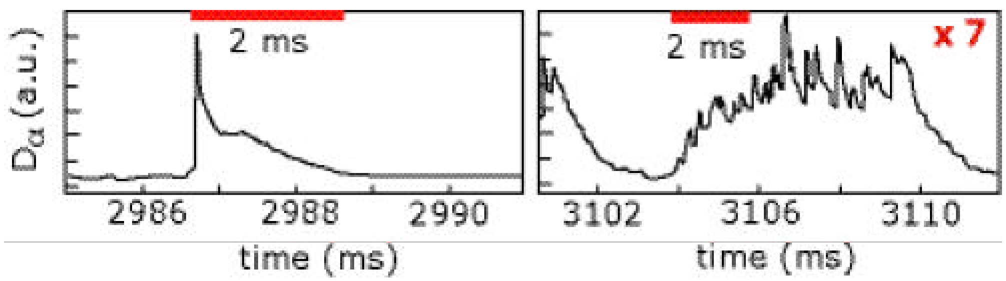
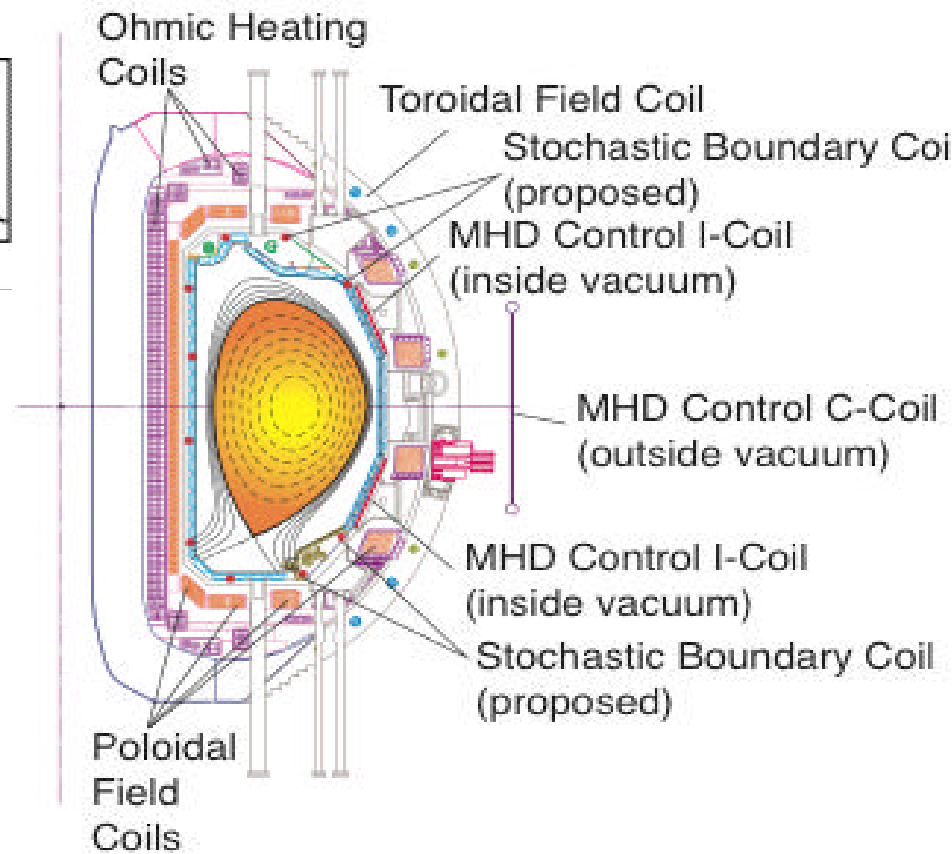
Experiments in DIII-D show that large ELMs can be suppressed with a stochastic boundary

- In these experiments the high impulsive loading due to ELMs is replaced with low level, long duration, oscillations that:

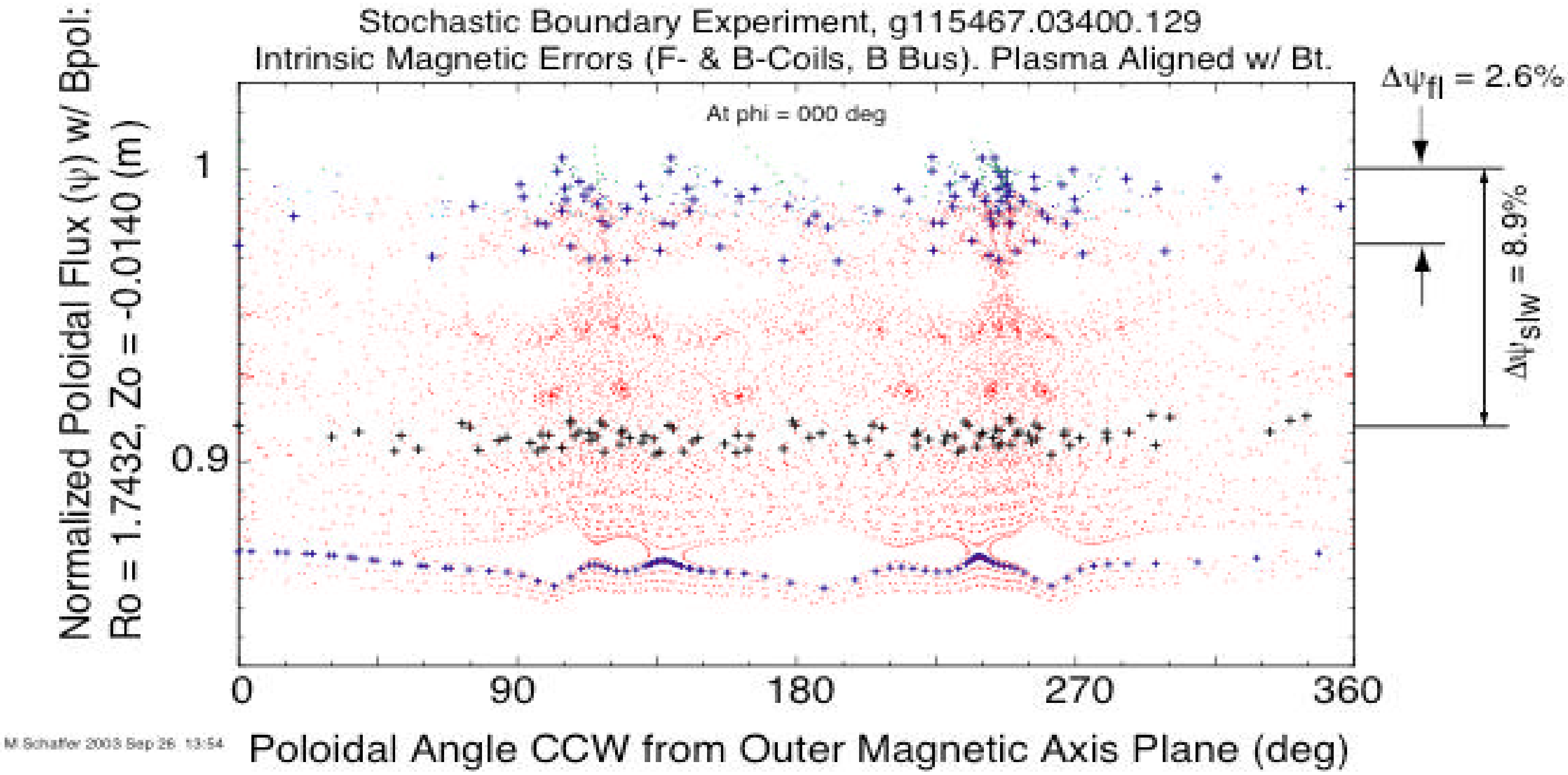


  > maintain good steady-state heat and particle exhaust,
  > eliminate large PMI erosion rates and
  > retain high core confinement with high performance pedestal profiles
- Field line integration (FLI) modeling results show that both “field errors” and external coil perturbations play an important role in controlling the ELMs

All the δb_r sources must be included in the ELM and PMI modeling



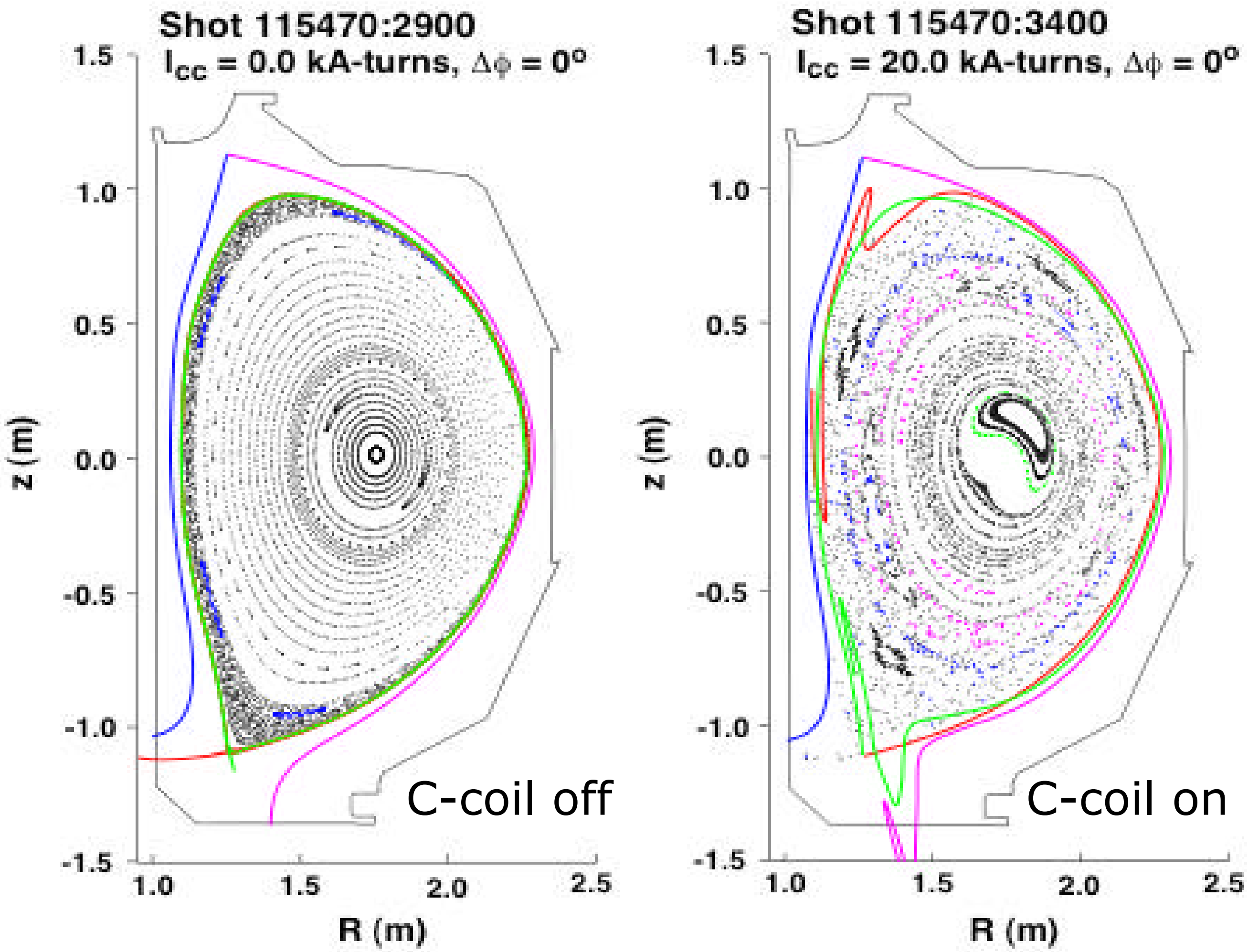
The structure of the stochastic layer is characterized by its width Dy_{slw} and poloidal magnetic flux loss Dy_{fl}



- Rectangular Poincaré plot showing a TRIP3D FLI calculation of the magnetic structure in DIII-D pedestal with **measured error fields only (no C- or I-coil)**.

TRIP3D modeling (no plasma response included)

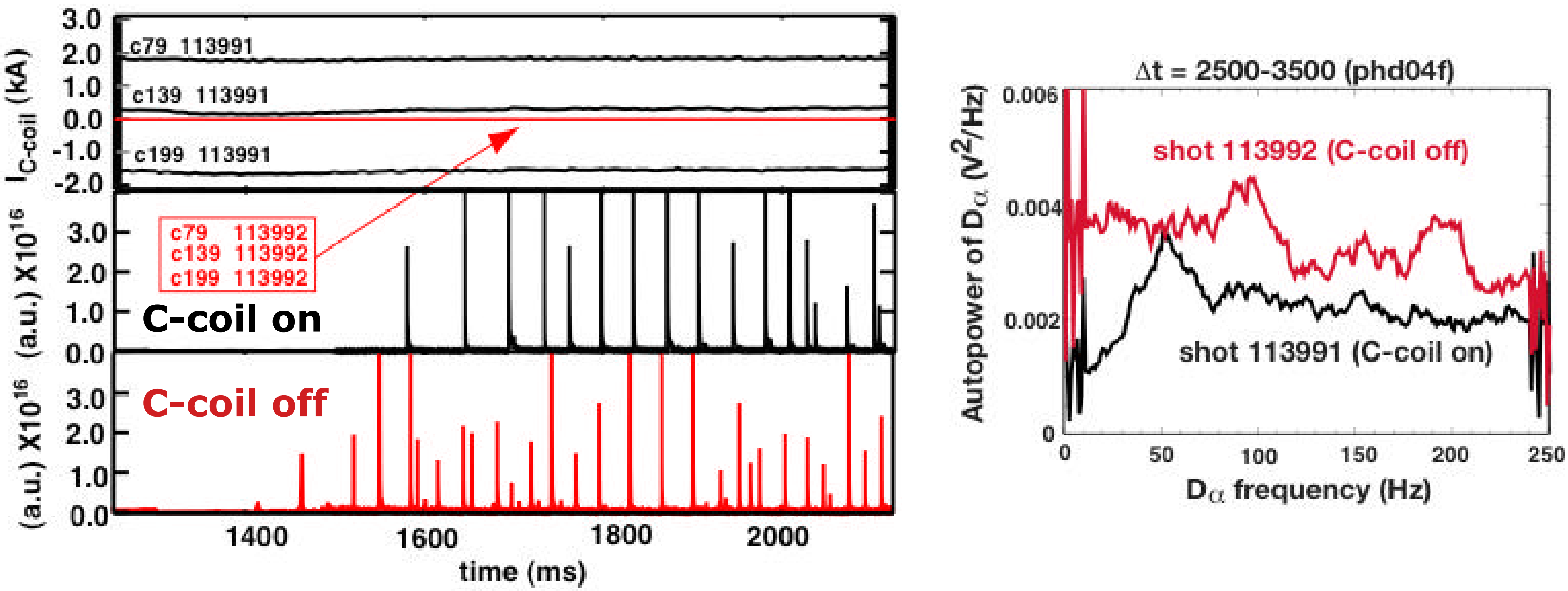
The correction coil (C-coil) can create a wide stochastic layer compared to that produced by intrinsic field errors



- With 20 kA-turns in the C-coil $\Delta\psi_{slw}$ increases from 6.2% due the f-coil error fields to 45.4% while $\Delta\psi_{fl}$ increases from 0.2% to 23.3%.
- Although the C-coil is typically operated well below 20 kA-turns for standard error field correction it produces a significant edge stochastic layer in most cases.

TRIP3D modeling (no plasma response included)

The C-coil has a substantial impact on ELMs in identical discharges with and without coil current



- The ELM free period is longer and the ELM frequency is lower with the C-coil operating in the standard error field correction mode.
- The ELMs are more irregular without the C-coil and have a broader power spectrum.

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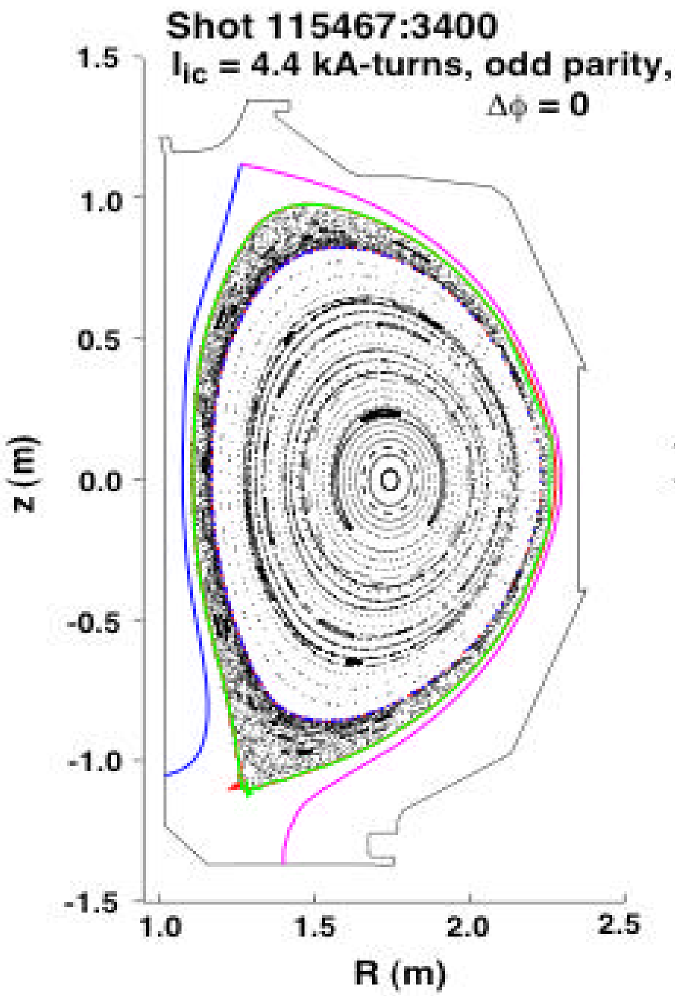
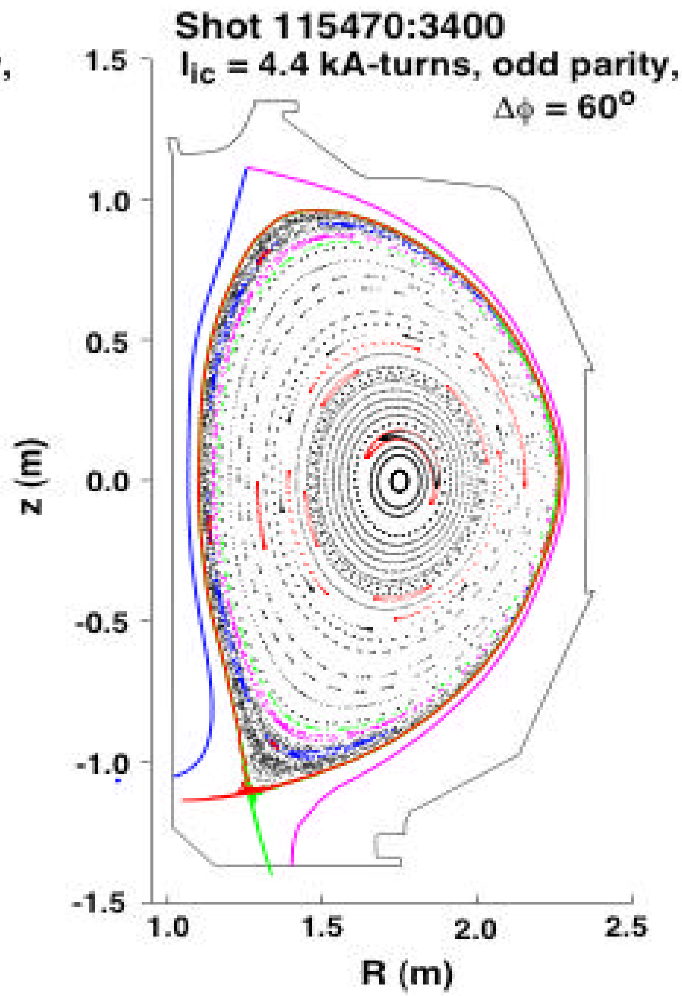
The I-coil produces a thinner stochastic layer than the C-coil but is more efficient for suppressing large ELMs





- The toroidal phase of the I-coil perturbation has a small effect on the stochastic layer due to a difference in the mixing with intrinsic error fields, with $\Delta\phi$=0, $\Delta\psi_{slw}$=12.6% and $\Delta\psi_{fl}$=1.7% while with $\Delta\phi$=60^o, $\Delta\psi_{slw}$=10.2% and $\Delta\psi_{fl}$=0.7%.
- Although the stochastic layer is thinner with the I-coil the effect on ELMs is larger.

TRIP3D modeling (no plasma response included)

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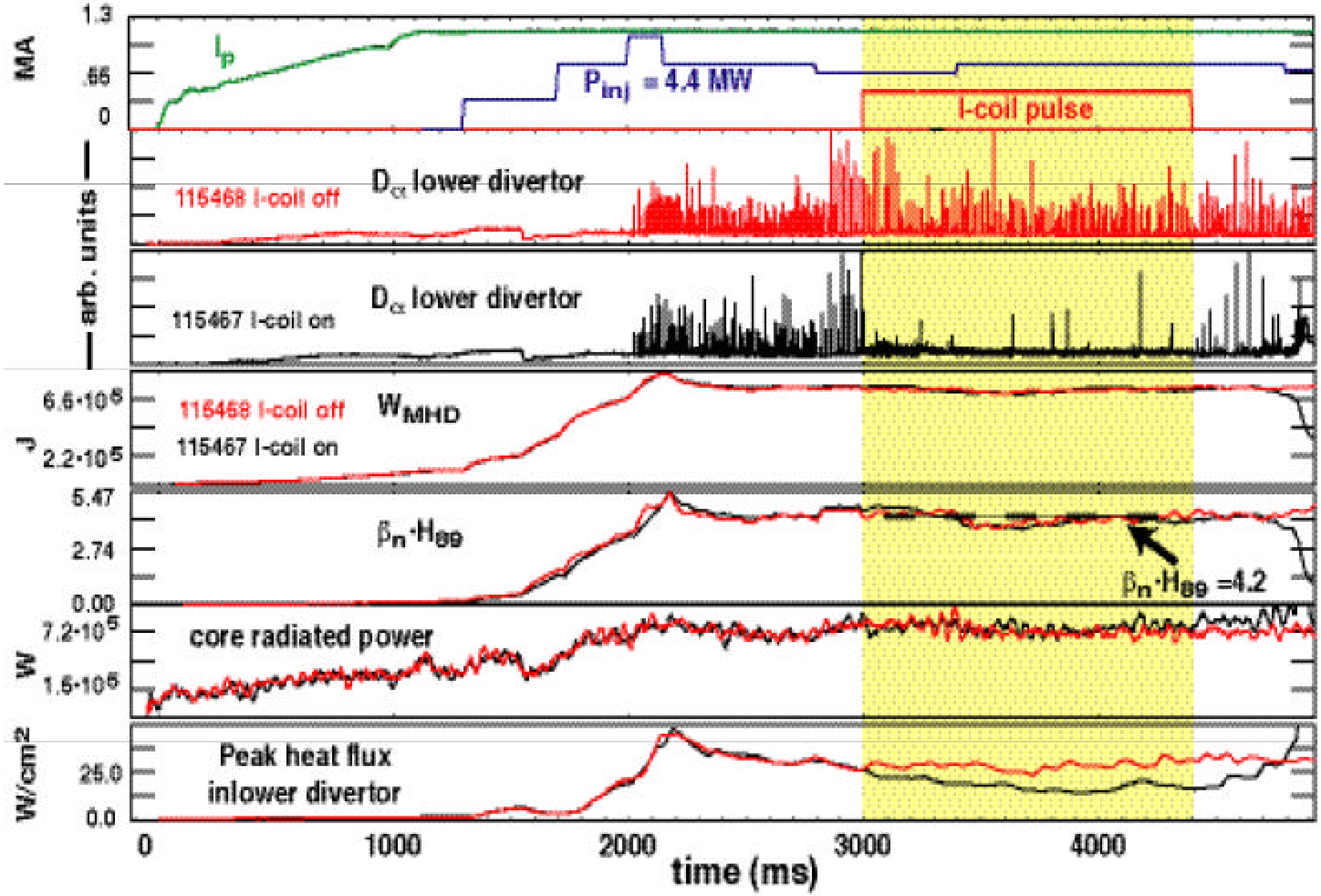
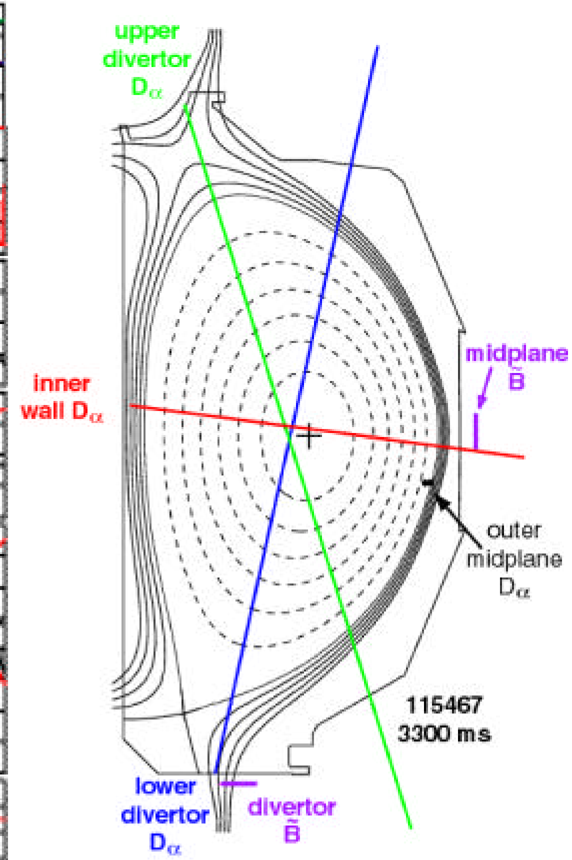
Large ELMs are suppressed without degrading the core confinement during the I-coil pulse

- Type I ELMs suppressed in high performance ELMing H-modes ($\beta_n \bullet H = 4.2$) with and edge resonant perturbation.





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An integrated 3D modeling approach is needed to address tokamak ELM and PMI issues

- Experimental data shows that edge 3D effects become significantly more important in high confinement tokamak regimes, particularly with respect to:
  - ELM control and PMI issues critical for ITER or advanced materials scenarios
- An integrated 3D modeling approach is need for the pedestal, SOL and divertor in order to address ELM and PMI issues critical for ITER
- Many of the numerical tools required to start exploring avenues for an integrated 3D modeling approach already exist within the PMI group:
  - UEDGE and b2.5 (axisymmetric 2D background edge/SOL/divertor plasma fluid with kinetic hydrogen neutrals)
  - WBC (kinetic 3D sputtering and near surface transport)
  - MCI (kinetic edge/SOL/divertor 3D impurity transport and atomic physics)
  - TRIP3D (3D magnetic field line integration)
  - E3D (kinetic 3D heat and momentum transport)
- A dedicated effort is now needed to couple these codes and to apply them to critical PMI issues facing ITER as well as for developing advanced materials scenarios relevant to future fusion applications